Design for Environment

Life Cycle Design Approach in SMEs *

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Abstract. This paper is guided by two premises. First, effective pollution prevention requires the demonstrated ability to decrease adverse environmental impacts at every stage of the life cycle of any given product. Firms that take full responsibility for the impacts of their products from cradle to grave experience high levels of organizational learning. A five-stage learning curve is proposed which stems mostly from the actions undertaken within a large firm or multinational context. The second premise is centered on the critical importance for small and medium-sized enterprises (SMEs) to 'green' their products. Based on a sample of 368 environmentally responsive SMEs, it is shown that they are making some progress towards dealing with the environmental impacts of their products, despite the fact that their product life cycle initiatives seem to be partial and limited in scope. They will, however, have to move faster along the proposed learning curve, since more advanced, stronger environmental performance will increasingly constitute an asset for selling their products on the international scene or for qualifying as a subcontractor or supplier. Furthermore, empirical evidence demonstrates that improved environmental performance encourages process innovations and enhances corporate image and liability management, but tangible economic returns such as cost containment and revenue generation seem to be harder to achieve.

Keywords: Competitiveness; environmental performance; design for environment (DfE); DfE; environmental product declaration; innovativeness; ISO 14000; product life cycle management; small and medium-sized enterprises (SMEs); SMEs

Introduction

Although there is a high level of uncertainty surrounding the accurate assessment of the environmental impacts of the ever-increasing rate of industrialization, pressures are mounting. Firms are being held more and more responsible for the adverse impacts of their products on the environment.

Small and medium-sized enterprises (SMEs) are important actors on the environmental scene, since they collectively have a high aggregate impact on the environment. SMEs in the UK, for instance, contribute an estimated 70% of all pollution generated (Rowe and Hollingsworth 1996). This figure, although largely unsubstantiated, has "taken on mythical statu" (Hillary 2000) and most researchers agree that SMEs' environmental impacts are largely contributing to the worldwide pollution load. Thus, it is of critical importance for SMEs to pay greater attention to the environmental performance of their activities and products.

This paper therefore focuses on firms' environmental performance. Our objectives are twofold: (i) to propose a transition model towards sustainable development; and (ii) to present empirical evidence of the initiatives taken by 368 SMEs to green their products and to assess the competitive advantages derived from such initiatives.

1 Environmental Performance: A Progressive Transition Model Towards Sustainable Development

A firm's environmental performance is a multifaceted concept which can be captured by certain indicators and initiatives (section 1.1) that could ultimately ensure sustainable development (section 1.2).

1.1 Environmental management systems, life cycle design approach and environmental product declarations

The diffusion of the ISO 14001 standard can be used as one international indicator of environmental consciousness in different countries, although it mostly reflects the position of multinationals and their subsidiaries. These large firms may actually capitalize on the fact that ISO 14001 is increasingly considered to be "a new global passport for international trade" (Marcus and Willig 1997). According to the latest statistics published by the International Network for Environmental Management (INEM), close to 70% of all ISO 14001 certifications are in Japan and Western Europe (INEM 2000). Environmental concerns run deep in Japan. Because of its much greater population density compared to other industrialized countries, the level of recycling in Japan is high, much higher than in the US for instance (Tietenberg 1998). Furthermore, some of the worst environmental disasters, such as the Minamata mercury poisonings, have occurred in this country (Shrivastava 1996), raising environmental awareness in the Japanese population and among its policy-makers.

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Based on worldwide ISO 14001 certifications, Germany is the leader in Europe with respect to the adoption of ISO 14001 standards, followed by Sweden, the United Kingdom, and the USA (INEM 2000). This comes as no surprise since Germany has a long tradition of initiatives to protect the environment. In 1978, for instance, Germany (West Germany at that time) initiated the first environmental labeling program, called the Blue Angel program. It also launched the ambitious Green Dot program, which requires that all producers accept responsibility for recycling all packaging associated with their products.

Increasingly, other countries in the European Commission are not only imposing take-back requirements on packaging, but are also obliging companies to accept responsibility for their products from cradle to grave. These regulations are gradually implementing the concept of 'extended producer responsibility' or 'product stewardship', which forces manufacturers to add end-of-life services to their product offerings (i.e. to take back the products once they have outlived their useful lives or to support end-users on how to adequately dispose of products), as well as to adopt product life cycle strategies.

The examination of the ISO 14000 standard's structure (**Fig. 1**) sheds some light on its scope. So far, most companies have focused on familiarization with and adoption of the organizational set of standards (black circles), which is similar to the European Eco-Management Audit Scheme (EMAS) in many respects. However, the standards corresponding to the Environmental Product Declaration (EPD) and Life Cycle Assessment (LCA) (white circles), and supporting product life cycle management, represent a totally new field of expertise. This explains the much slower diffusion rate of the ISO 14020 and 14040 series. Furthermore, in order to render national EPD systems cost effective, "such declarations shall be based on existing ways of working for implementing environmental management systems (e.g. ISO 14001 and EMAS)" (SEMC 1998), giving place to a logical sequence in the adoption of environmental standards.

The leadership of some European countries in improving products' environmental performance has led to some remarkable innovations. In Sweden, for instance, close to twenty Type III Environmental Product Declarations have already been published (SEMC 2000). An eloquent example of such an achievement is Volvo Cars' Environmental Product Declaration for the Volvo S40/V40 2.0 LPT, manufactured at the Born plant in the Netherlands (Fig. 2).

In order to be accurate and reliable, Environmental Product Declarations (ISO 14025) must rely on the complete and rigorous LCA of product systems (in accordance with ISO 14040, 14041, 14042 and 14043) and require thorough reviews by a third party. The ISO 14040 standard series involves the application of LCA for product systems. LCA covers the entire life cycle of the product, from raw material extraction to production, use and end of life. LCA comprises three main steps: i) ISO 14041 - the data inventory of inputs (materials, energy, water) and outputs (emissions, byproducts, wastes) crossing the boundaries of the product system under study, ii) ISO 14042 – the evaluation of potential environmental impacts stemming from the compiled inventory, iii) ISO 14043 – the interpretation of the results from the two previous steps with respect to the objectives of the project (ISO 1998a).

As illustrated in Fig. 2, one of the most challenging aspects of the LCA approach is the acquisition of the life cycle inventory data, which come from different internal and external sources (ISO 1998b). Internally, the required information is provided by the different services or departments, such as procurement, engineering, manufacturing, distribution and sales; thus, a high level of internal functional integration is required to render the data acquisition process as smooth as possible in terms of data availability, uniformity and format. A large proportion of the environmental product data also comes from external sources, located upstream and downstream in the product value chain, and involves the participation of tens, and even hundreds, of business partners such as suppliers, subcontractors and distributors. The preparation of a Type III Product Declaration therefore demands strong collaboration between the business partners, and, thus, holds great potential for improving environmental awareness and performance of entire supply chains.

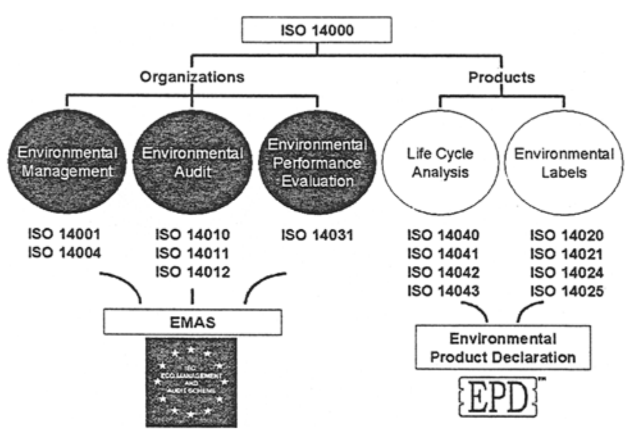

Fig. 1: ISO 14000 standard structure, EMAS and EPD (adapted from SEMC 2000)

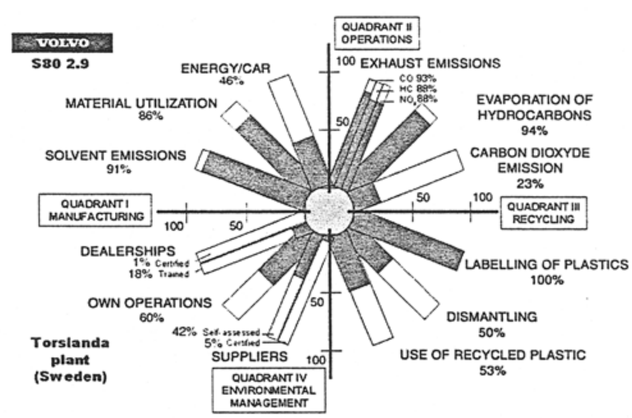

Fig. 2: Volvo S40/V40 2.0 LPT Type III environmental product declaration (Volvo Car Corporation 1999)

In addition to LCA, the Environmental Product Declaration must provide information of a general nature about the manufacturer's specific processes and environmental actions, such as the presence of certified EMSs (quadrant IV, Fig 2). An EMS consists of the essential managerial procedures that assist a firm's efforts to adequately organize its environmental initiatives (Sayre 1996). It is important to note that an EMS based on ISO 14001 does not impose product life cycle requirements. However, firms interested in improving the environmental performance of their products through the use of life cycle design strategies would normally benefit from the previous deployment of a corporate EMS, helping in the standardization of fundamental procedures and raising employees' awareness and motivation towards environmental issues, thus providing a higher level of internal functional integration.

Fig. 2 shows that Volvo has overcome most of the problems related to data availability, by enforcing standards for data acquisition and data format applicable to all functions of the organization. It also illustrates the fact that Volvo is making progress in greening its products by rigorously following a holistic life cycle design approach. Most striking of all, after a decade or so of focused attention on product life cycle issues, Volvo has also had to convince strategic business partners to use these standards and disclose information that is traditionally kept secret. Consequently, Volvo has developed a unique knowledge of product life cycle management and has built new strategic competencies.

1.2 A progressive transition model towards sustainable development

The adoption of more sustainable development patterns is quite challenging. According to the World Business Council for Sustainable Development (WBCSD), development is sustainable when it "meets the needs of the present without compromising the ability of future generations to meet their own needs". The case of Volvo illustrates that taking full environmental responsibility for products is a lengthy learning process. Laggard firms eager to catch up could proceed in a systematic manner and follow the five-stage sequence illustrated in **Fig. 3**.

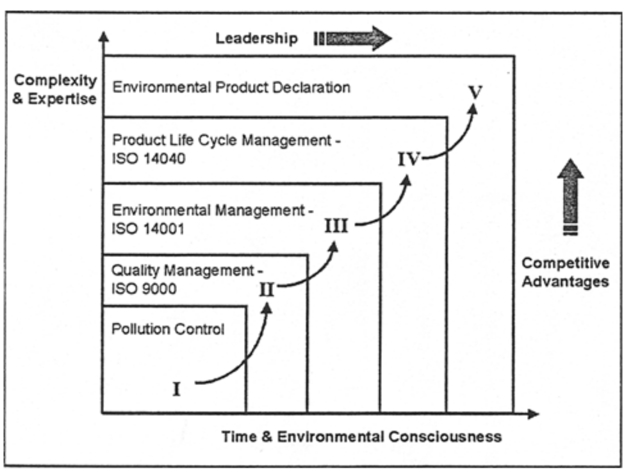

Fig. 3: Environmental product declaration: a five-stage learning curve (adapted from Talbot 1999)

During **stage I**, a firm becomes aware of the need to reduce the environmental burdens created by its products and undertakes some positive actions, sometimes at the request of employees or stakeholders. Stage I can be characterized by environmental improvisation rather than a systematic approach. Pollution control during stage I could be qualified as reactive since it focuses mostly on end-of-pipe technologies.

Stage II (ISO 9000) may be considered as useful and preliminary to stage III (ISO 14001). In fact, ISO 9000 and 14001 share some similarities with either their structure or the management issues they address. Actually, the implementation of an ISO 9000 quality management system formalizes the firm's processes while focusing on product quality and customer satisfaction, whereas the implementation of an ISO 14001 environmental management system formalizes processes related to the management of the environmental aspects of the firm's operations

Other striking similarities exist between quality management and environmental management, such as the goals of 'zero defects' and 'zero pollution'. Furthermore, it has been shown that previous experience with ISO 9000 (stage II) significantly facilitates the adoption of ISO 14001 (**stage III**) and that the implementation of ISO 14001 is in general faster and less costly than the first experiment with ISO 9000 (Cichowicz 1997).

The implementation of product life cycle management (**stage IV**) takes into account all the product's environmental impacts during its entire life cycle. This therefore departs from previous piecemeal initiatives and requires the firm to tackle a very broad spectrum of environmental initiatives. Consequently, stage IV is more complex than stage III because a high level of internal and external functional integration is required along the entire product value chain. The implementation of an Environmental Product Declaration (**stage V**) represents a valuable marketing weapon which yields considerable competitive advantages, while at the same time clearing a path to sustainable development.

So far, only a few leading firms have developed this impressive range of expertise, which may be fairly difficult to imitate in the short term. In general, SMEs have not progressed very fast, and most are not even at stage I, even though they may have reached stage II with respect to ISO 9000. They will therefore have to catch up, because firms that lag behind on the learning curve (Fig. 3) will be exposing themselves to the erosion of their competitive positioning in the very near future.

2 Environmental Performance of SMEs: Some Empirical Evidence

SMEs are important actors in industrialized economies and consequently must bear their share of responsibility for the degradation of the environment. We therefore conducted a survey to assess the environmental performance of SMEs and the benefits they can derive from their environmental initiatives.

2.1 Methodology

A thoroughly pre-tested questionnaire was distributed to Canadian SMEs from four different industrial sectors: wood products [SIC 25], printing [SIC 28], electric/electronic products [SIC 33], and metal products [SIC 30]. The survey required the participation of three respondents per firm, namely the CEO, the marketing director, and the head of operations/manufacturing. Only SMEs which were engaged in environmental initiatives to some extent were retained. The survey design allowed for quota sampling, and the pre-set objective was to obtain at least 75 responding firms from each industry, in order to obtain statistically robust results. The results from a sample of 368 environmentally conscious SMEs (78 firms from the wood product sector, 74 firms from the printing sector, 119 firms from the fabricated metal product sector and 97 firms from the electric/electronic product sector) are presented in the next section.

Special attention was directed towards assessing the reliability of the results. First, in order to detect the presence of particular biases among the different types of respondents (CEO, head of operations/manufacturing, marketing director), inter-rater reliability tests were run. The results ranged from very reliable[1] to reliable. Second, the variables retained for this survey consist of multiscale constructs (Appendices 1 and 2). Construct reliability was very satisfactory, ranging from 0.78 to 0.97, far exceeding thresholds set by Van de Ven and Ferry (Van de Ven and Ferry 1980).

2.2 Environmental product declarations in SMEs: Industrial aggregates

Fig. 4 illustrates the initiatives undertaken by the 368 environmentally conscious SMEs with respect to the latest product they had developed. Industrial aggregates (i.e. average scores for environmental initiatives per industrial sector) are presented along four quadrants: green manufacturing, green design and recycling (quadrants 1, 2 and 3), and the extent to which EMSs are present (quadrant 4). The operational measures retained for assessing environmental initiatives are

[1] A perfect score indicates that the three respondents from the same firm submitted exactly the same answers, probably after thorough consultation, although they did send separate questionnaires.

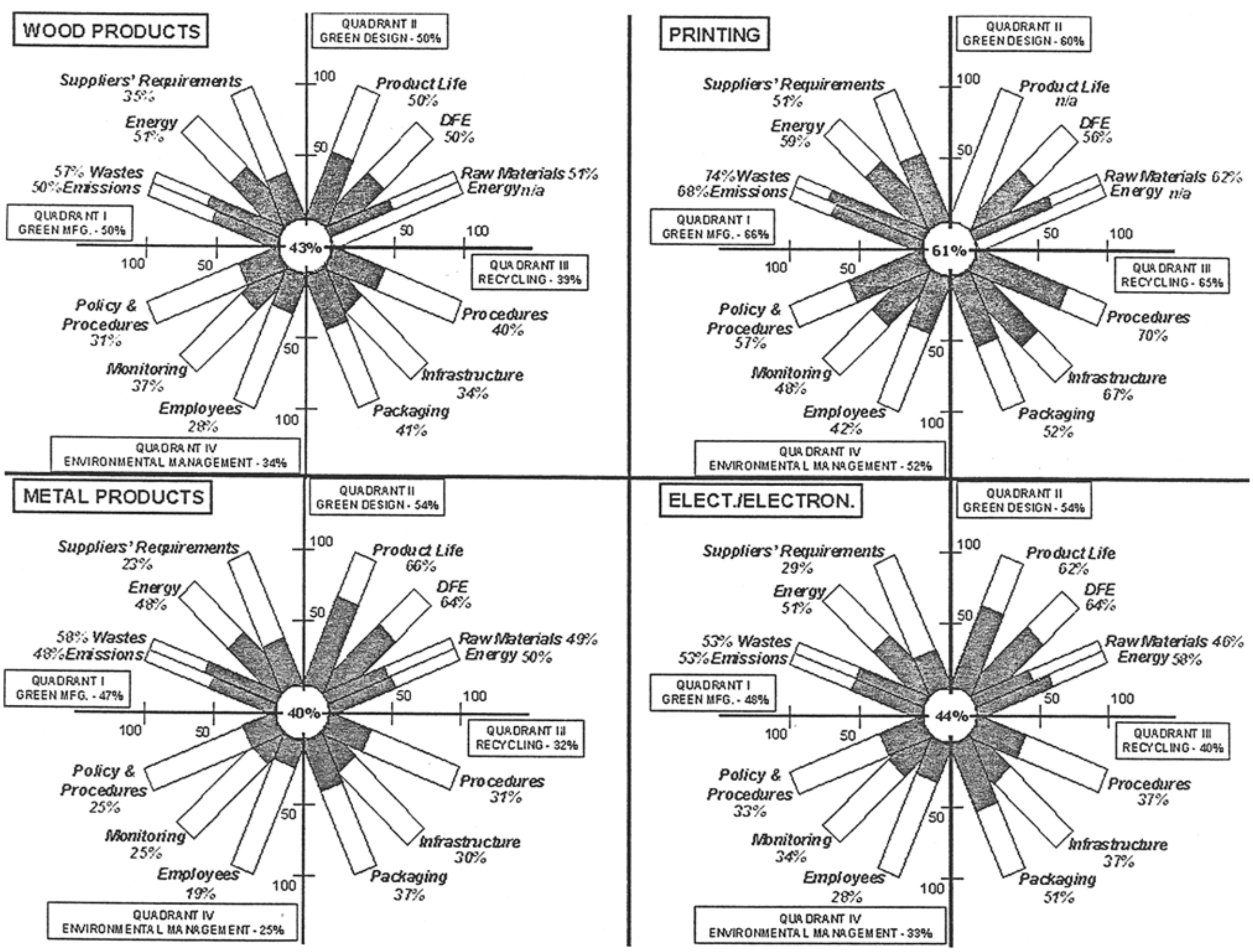

Fig. 4: Environmental product declarations in SMEs: industrial aggregates [averages were calculated for the fourteen groups of variables, then for the four group of activities (each quadrant) and then for each sector (the percentage at the center of each daisy flower)]

displayed in **Appendix 1**. Although some minor modifications were made to reflect the particular characteristics of the four industrial contexts and of SMEs, the presentation of the results in Fig. 4 is in line with the Environmental Product Declaration and similar to Volvo's declaration.

The overall environmental performance for all sectors is relatively low (below the 45% mark with the exception of the printing sector which scores 61%). These results are probably representative of the low level of environmental initiatives as yet undertaken by SMEs in most industrialized countries.

A closer examination of Fig. 4 reveals some interesting results:

(i) The printing sector displays the highest scores, most probably due to past experience: a cleaner manufacturing process (for instance, the substitution of solvents in blanket and press washes) and recycling [2] (for example, the use of recycled, chlorine-free, soy-based inks and the existence of established recycling procedures for magazines and newspapers) have been in place for a decade or more. The printing sector's high score in recycling can be explained in part by the short life cycle nature of their products. This leads to highly visible wastes which raises the need for adequate end-of-life measures. Under intense scrutiny, the printing industry also scores the highest for EMSs. Overall, this industry's environmental performance may be related to the fact that it is easier to green in that particular industry, at least in comparison to the other three.

(ii) The electric/electronic product sector is in second place for green design and recycling. Because of the inherent complexity of these products, integrating environmental considerations into the design process presents some difficult challenges. Among these challenges, the selection of more environmentally benign raw materials and the reduction of energy consumption rank high, although DFE (design for the environment, i.e. design the product to be easy to repair, manufacture, disassemble and recycle) and increased product life score even higher. These rather high scores may be partially explained by the fact that the sector is R&D-intensive. Waste disposal problems for the electric/electronic product sector are also particularly acute: more than 10 million PCs and some 350 million electrical appliances end up in dumps each year in the US alone. These problems seem to be acknowledged to a certain extent, but SMEs in that industry place more emphasis on green manufacturing and green design.

(iii) The fabricated metal product industry shares some similarities with the electric/electronic product industry. It also emphasizes green design, green manufacturing and recycling.

(iv) The Canadian forest industries are under considerable pressure from various groups (ecologists, conservationists, aboriginal peoples, etc.) to improve forest management practices and impose strict regulation on harvesting and silviculture. The wood product sector faces environmental challenges for cleaner industrial processes such as wood preservation (which requires the use of oil-borne or water-borne chemicals such as pentachlorophenol or copper naphthenate) and has thus undertaken several initiatives to green its products (second quadrant) and manufacturing processes (first quadrant). Some efforts are also being made to recycle.

(v) Except in the printing industry, SMEs display very low scores for EMSs. This is intriguing since the implementation of an EMS is often viewed, at least in the context of a large firm, as a critical first step before moving into product life cycle-based initiatives. The rather informal context of SMEs may explain this result. It has been shown that these firms do not usually have a formalized strategic plan.

The implications of the results presented in Fig. 4 are far-reaching. Considering the informal structure of SMEs and their low score on the EMS axis, it is reasonable to suspect that the impacts of their environmental initiatives are alleviated. Do they base themselves on rigorous LCA or life cycle design (LCD) approaches? Probably not, as their product life cycle initiatives seem to be partial and limited in scope. There is no evidence demonstrating that SMEs are acting in accordance with a coherent environmental strategy: this could imply adopting a product life cycle improvement path aimed at coordinating the several environmental initiatives in the context of an effective pollution prevention program.

Environmental initiatives in these SMEs are probably guided either by large corporate customers with stronger environmental wisdom or, in some cases, by the desire to imitate a competitor's tactics. This may lead SMEs towards 'plug and play' solutions that are not totally adapted to their specific situations and/or products. The results strongly suggest that most SMEs are at stage I, and that some SMEs are indeed moving along the learning curve proposed in Fig. 3, since some are ISO 9000 certified (stage II) and a few are considering the implementation of ISO 14001 EMS (stage III) within the next two years. However, none of the firms in our sample have reached stages IV and V yet. The wider implementation of ISO 14001 EMS would certainly help SMEs in structuring a coherent environmental strategy leading to these higher level stages.

2.3 Competitive advantages gained by SMEs from increased environmental performance

What are the benefits of improved environmental performance within an SME context? For the four industrial sectors, **Fig. 5** displays the average level of attainment for six sets of benefits, namely (i) liability management and corporate image, (ii) revenue generation, (iii) cost containment, (iv) managerial innovation, (v) process innovation and (vi) product innovation. The operational measures for these benefits are available in Appendix 2. The first striking result that can be observed from Fig. 5 is that the most environmentally concerned sector, i.e. the printing sector, seems to derive more benefits from its initiatives than the other three sectors. In the same line of thought, the least environmentally concerned sector, namely the fabricated metal product sector, also displays the lowest benefits. The second finding is that the most positive outcome seems to be rather intangible: liability management and corporate image is the most significant benefit for

[2] Recycling is not an LCA activity per se, but it is an important component of the overall product life cycle management system.

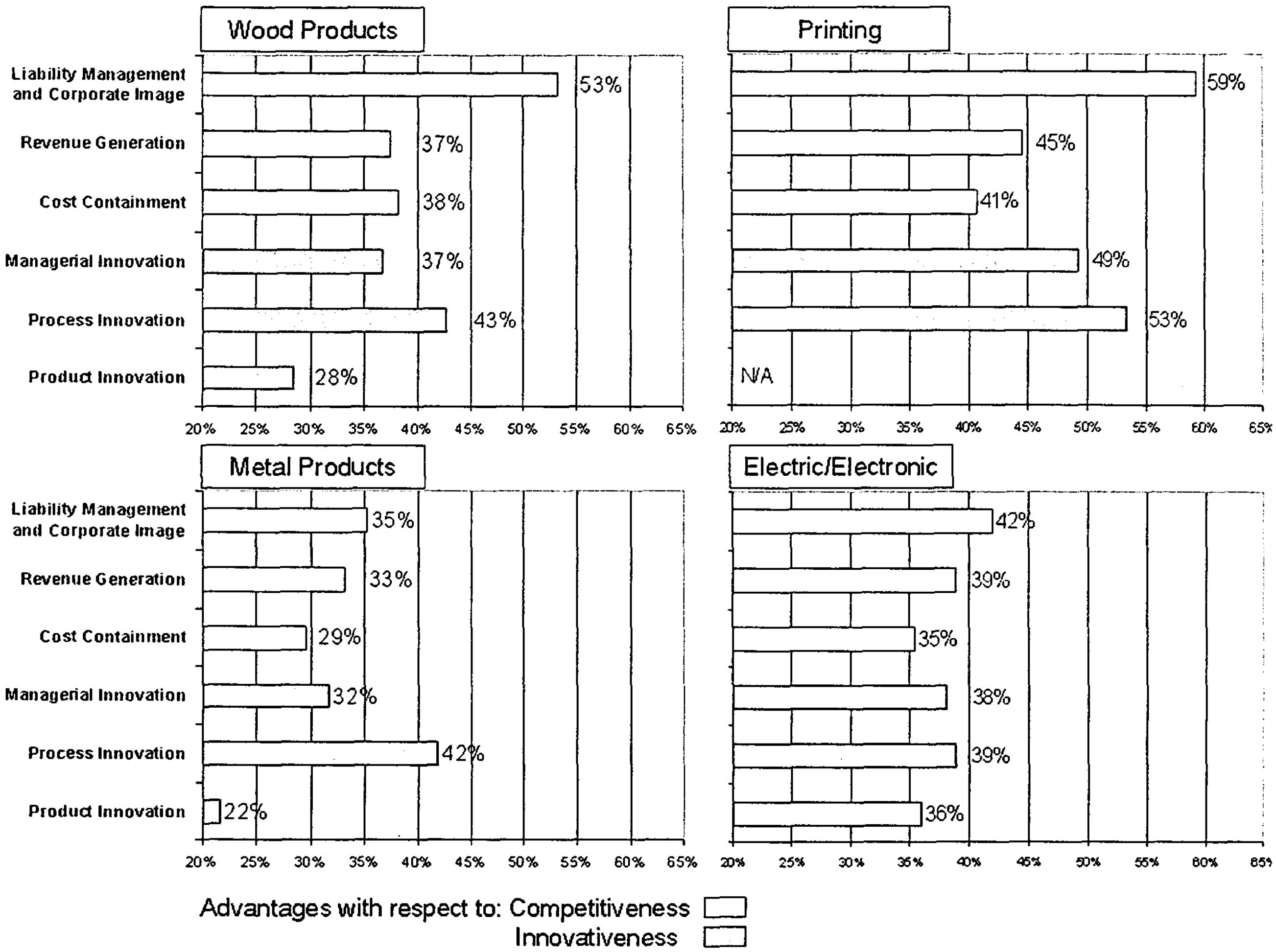

Fig. 5: Environmental performance and competitive advantages

the wood product sector, the printing sector and the electric/ electronic sector and ranks second for the fabricated metal product sector. The third observation is related to innovativeness: environmentally conscious SMEs seem to better capitalize on process innovations rather than on product or managerial innovations. Finally, increased environmental performance does translate into some positive financial outcomes in terms of cost reductions and revenue generation.

The real message of Fig. 5 is that turning environmental initiatives into benefits can be achieved: outcomes are indeed positive for SMEs from the four sectors. However, materialization of hard financial benefits is more difficult than gaining more intangible benefits.

3 Conclusion

Two premises have guided the discussion in this paper. First, effective pollution prevention requires the demonstrated ability to decrease adverse environmental impacts at every stage of the life cycle of any given product. This requires not only inter-functional integration within firms, but also upstream and downstream integration with business partners such as suppliers, subcontractors, distributors and customers. Firms that take full responsibility for the impacts of their products from cradle to grave experience high levels of organizational learning. A five-stage learning curve has been proposed and illustrated by the actions undertaken within a large firm or multinational.

The second premise is centered on the critical importance for SMEs of greening their products. SMEs have been largely ignored in the environmental literature (for an exception, see Hillary 2000), although they collectively have a high aggregate impact on the environment. Based on our sample of environmentally responsive SMEs, it has been shown that they have made some progress towards dealing with the environmental impacts of their products and that they have gained some competitive advantage from their environmental initiatives. They will, however, have to move faster along the proposed learning curve, since more advanced, stronger environmental performance will increasingly constitute an asset (and even an a priori requirement) for selling their products on the international scene or for qualifying as a subcontractor or supplier.

Addressing the environmental challenge is a major strategic issue for firms of all sizes. Providing effective and feasible means to prevent an environmentally destructive behavior represents a formidable task for managers, researchers and public policy-makers. Undoubtedly, the quest for sustainable development will require increased levels of cooperation from all parties involved.

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Appendix 1: Life cycle design approach [3]

Green design
Raw Materials
• Choose raw materials that can be recycled or are less harmful to the environment
• Reduce the amount of raw materials
Energy
• Reduce the energy that will be necessary to use/operate the product
Product's Life
• Increase the product's useful life
Design for Environment (DFE)
• Design the product to accommodate multiple future users
• Design the product to be easy to repair
• Design the product to be easy to disassemble
• Design the product to be easy to recycle
• Design the product to be easy to manufacture
Green manufacturing
Suppliers' Requirements
• Select subcontractors based on their environmental performance
Energy
• Reduce the energy required for manufacturing and assembling the product
Emissions
• Reduce polluting emissions
• Treat or capture polluting emissions
Waste
• Minimize waste
• Ensure appropriate storage/dumping of waste
Recycling
Procedures
• Establish recycling procedures
• Establish appropriate procedures for dangerous materials at the end of product's life cycle
Infrastructure
• Ensure that recuperation infrastructures exist
Packaging
• Make packaging recyclable

[3] The product life cycle-based initiatives are mainly derived from (EPA1992) and (OTA,1992). Environmental management practices are adapted from (Sayre 1996). Measurements are based on 7-point Likert scales, from no effort or strogly disagree (= 1) to considerable effort or strongly agree (= 7).

Appendix 1: Life cycle design approach (cont'd)

Environmental management
Policy & Procedures
• Written, detailed environmental policy
• Proactive environmental policy beyond compliance to legislative requirements
• Establishment of quantifiable environmental objectives
• Documented procedures for EMS
Monitoring
• Monitoring environmental costs and benefits
• Environmental audit on a regular basis
• Reassessment of EMS on a regular basis
Employees
• Establishment of roles and responsibilities with respect to environmental programs
• Appropriate training for employees
• Employee remuneration and promotion based on environmental objectives

Appendix 2: Competitive benefits derived from environmental initiatives [4]

Competitiveness
Liability management and corporate image: the degree to which environmental initiatives have allowed:
• reduction in legal fines and penalties
• enhancement in corporate image
Revenue generation: the degree to which environmental initiatives have allowed:
• increased market share
• increased customization
• increased profits
• increased opportunities for new products
Cost containment: the degree to which environmental initiatives have allowed:
• cost reductions with respect to manufacturing/production
• cost reductions with respect to inventory and handling
• cost reductions with respect to transport and distribution
Innovativeness
Managerial innovations: the degree to which environmental initiatives have allowed:
• introduction of new management systems
• acquisition of new competencies with respect to R&D
• acquisition of new competencies with respect to production
• acquisition of new competencies with respect to marketing
• increased awareness of environmental requirements for different markets
• increased awareness of environmental technologies
Process innovations: the degree to which environmental initiatives have allowed:
• introduction of more efficient manufacturing production technologies
• cost reductions with respect to raw materials
• cost reductions with respect to energy consumption
• improvements with respect to work conditions
Product innovations: the degree to which environmental initiatives have allowed:
• improvements with respect to product design
• improvements with respect to product quality
• improvements with respect to product security
• new product developments

[4] Measurements are based on 7-point Likert scales, from strongly disagree (= 1) to strongly agree (= 7).

Biography of Authors

Dr. Élisabeth Lefebvre is a Professor at École Polytechnique de Montréal. She is the coordinator of graduate programs in the Management of Technology. Professor Lefebvre is also co-director of Center ePoly, the Electronic Commerce Center of Expertise of École Polytechnique de Montréal.

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Stéphane Talbot is a Ph.D. candidate in the program of Management of Technology at École Polytechnique de Montréal. His thesis focuses on the integration of environmental concerns into product development processes.